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A PROCEDURE FOR RIVER CROSSING IN PRECISE LEVELING.(U)
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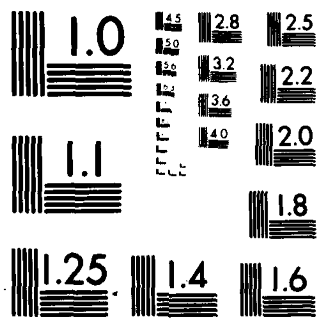

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A procedure for transferring precise level across a river based on simultaneous measurement of vertical angles to targets mounted on level rods, with a Wild T-3 theodolite, and successfully employed on the Senegal River Basin Survey Project, is described. Different methods available for computing the difference in elevation from observed vertical angles are discussed, and various checks in the intermediate and the final computed results are pointed out. The result of a test comparison of the distance computed from observed vertical angles with one measured with EDM equipment is also reported. It is

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A PROCEDURE FOR RIVER CROSSING IN PRECISE LEVELING

Hugh N. Caddess
Geodesist, Defense Mapping Agency
Currently Geodetic Advisor to A.I.D.
Senegal River Basin Survey Project
Dakar, Senegal

Mushtaq Hussain, Ph.D.,P.E.
Professor, School of Engineering
California State University, Fresno
Fresno, California 93740

BIOGRAPHICAL SKETCH

Hugh N. Caddess graduated from Texas A & M University in 1960. He has been a geodesist with the Defense Mapping Agency since 1962. He is currently assigned to the A.I.D. sponsored Senegal River Basin Survey Project as Geodetic Advisor. He has worked out several new observing techniques for special survey problems in the past.

Mushtaq Hussain graduated in Civil Engineering from Pakistan Engineering College in 1954 and joined the Survey of Pakistan department in 1955. As U.N. Fellow, he spent one year at the USC&GS for training in Geodetic Surveying. He was appointed Assistant Surveyor General in 1970. He received Doctoral degree in Photogrammetry from the University of Washington, Seattle, in 1973. He then worked as R & D Engineer with Teledyne Geotronics in Long Beach, California, and has been, since 1978, on the faculty of California State University, Fresno. He is a licensed Civil Engineer in California and is consultant for geodetic and photogrammetric survey projects.

ABSTRACT

A procedure for transferring precise level across a river based on simultaneous measurement of vertical angles to targets mounted on level rods, with a Wild T-3 theodolite, and successfully employed on the Senegal River Basin Survey Project, is described. Different methods available for computing the difference in elevation from observed vertical angles, are discussed and, various checks in the intermediate and the final computed results are pointed out. The result of a test comparison of the distance computed from observed vertical angles with one measured with EDM equipment is also reported. It is apparent that the instrument pointing error and the atmospheric conditions play the key roles in river crossing. The results obtained using this procedure with a T-3 theodolite are comparable to those achievable through other methods commonly used for river crossing.

INTRODUCTION

The primary consideration in differential leveling is to maintain the equality in the length of the back and the forward sights at every instrument set up. However, when the level line is required to be carried across unspanned and wide water bodies, the equality in the length of sight cannot be enforced. Special observation procedures must then be used to transfer precise level across the obstacle. Such methods are designed to balance the errors in height determination due to the instrument collimation, the atmospheric refraction and the earth curvature.

A very common method of leveling for, what is usually known as "river crossing" or "valley crossing", has in the past, involved observations made to targets mounted at known heights on a precise level rod, with a precise leveling instrument of the Wild N-III type, which has a graduated tilting micrometer screw. This method has been successfully used and described by the National Geodetic Survey(2). It is basically designed to determine the reading on the far rod corresponding to a level line of sight, indirectly, from a set of three micrometer readings recorded while sighting to the top and the bottom targets and for the level sighting position.

There has been a considerable interest in the development and use of auto-collimating levels during the past decade. Since the line of sight for such a level cannot be tilted appreciably, the conventional method of river crossing cannot be used. A special method using an auto-collimating level (Zeiss Ni-2) has been reported by R. M. Berry of U.S. Lake Survey(1). This method employs optical wedges to measure the small angles between the two targets, requires two instruments on each side of the river and follows a system of balanced symmetrical observations.

In order to run high precision level lines as the primary vertical control for the Senegal River Basin Survey Project, Teledyne Geotronics chose the Zeiss Ni-002 level. This auto-collimating level has been in use in the National Geodetic Survey and has met the high precision accuracy standards. Special attachments are apparently not available for use with this instrument for river crossing. Consequently, a different approach was needed to transfer level across the Senegal River at half a dozen crossing sites. Hugh Caddess, as Advisor for the project, devised an alternate method of river crossing based on vertical angle measurement with Wild T-3 theodolite. The method was discussed with Mushtaq Hussain during his visit to Senegal as consultant to Teledyne Geotronics, in summer 1979, and some preliminary test measurements were jointly obtained. This method has since been successfully used at Dagana crossing. This paper presents the principle, the procedures for observation and data reduction and the results achieved so far.

THE PRINCIPLE AND OBSERVATION PROCEDURE

The principle of determining the difference in elevation between the marks on the two sides of the river is shown in

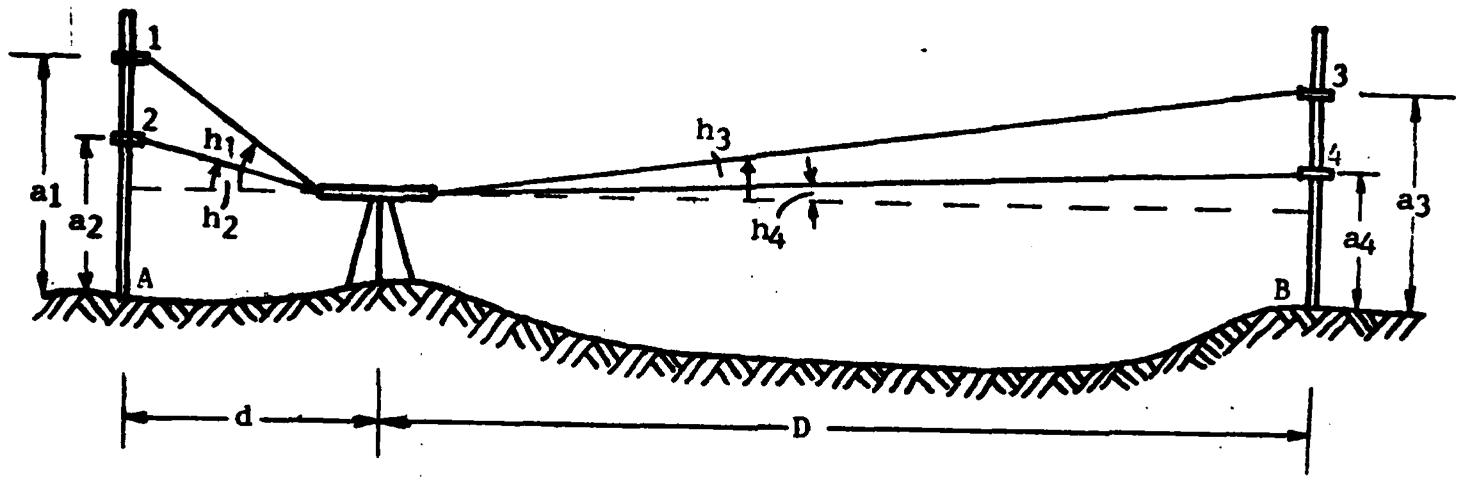
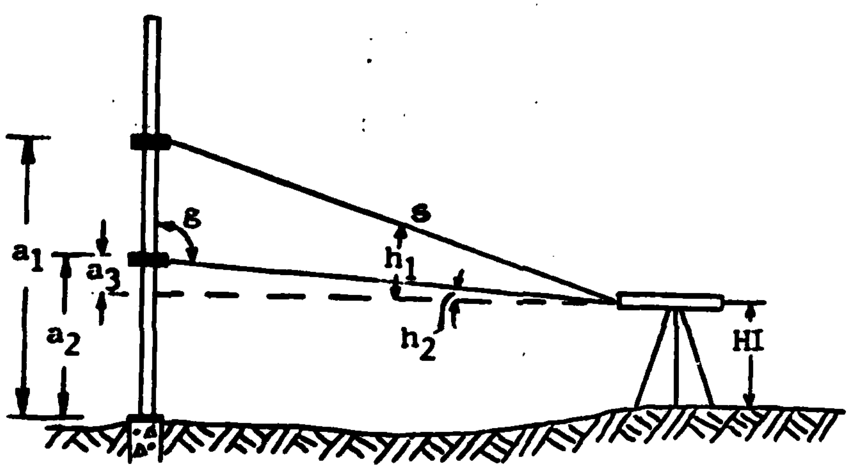


Fig.1 Instrument Set Up for River Crossing



$$s = \frac{(a_1 - a_2)\sin g}{\sin(h_1 - h_2)}\;;\quad g = 90^\circ + h_2$$

$$d = s \cos h_1$$

$$a_3 = d \tan h_2$$

$$HI = a_2 - a_3$$

$$HI = a_2 - \frac{(a_1 - a_2)\sin(90^\circ + h_2)}{\sin(h_1 - h_2)} \cos h_1 \tan h_2$$

Fig.2 Geometry of Height of Instrument Determination

Fig. 1 and 2. Two targets are mountedon Kern level rod on each side and simultaneous vertical angle observations are made with T-3 theodolite. The set ups are such that distance between a theodolite and the targets across the river is the same for both the instruments. The targets used are black with a yellow stripe in the middle, with a provision to change from narrow stripes to wide ones. If the height of the targets above the rod base can be accurately determined, the rod readings corresponding to the level line of sight can be interpolated to derive the difference in elevation.

The available targets are of poor design, as no definite relationship between the cursor and the center of the yellow stripe can be established. Besides, due to the poor clamp design, this relationship does not seem to be consistent. In addition to having unsatisfactory cursor for reading the target heights, the center stripes appear irregular. This poses the basic problem of guessing what an observer across the river would choose for the center when he makes a pointing and to determine the height of that spot. These problems have to be overcome through observing procedure.

Observing Procedure

Vertical angle observations are first made to determine the height of the instrument(HI in Fig.2). Observations are then made to determine target heights. A series of 40 pointings are made to targets across the river, resulting in 10 vertical angles to each target in each of the circle left and right positions. This is followed by a new set of observations made to determine HI and the target heights. The observers then swap places and the above procedure is repeated. Such observation data obtained at Dagana crossing in December, 1979 is shown, in part, in Fig. 3 and 4.

A single value of the difference in elevation between the two marks on opposite sides of the river is computed from the set of observations by both observers on each side of the river. Two such determinations on each day for two days constitute a complete river crossing, provided results appear acceptable. Since each observer makes 160 pointings on each side of the river, a complete river crossing would be computed from a total of 640 pointings which are evenly balanced and distributed. Some details of the procedure are described.

Determination of Height of Instrument

The determination of HI is made by pointing on three different graduations on the invar strip of the level rod. The central graduation selected corresponds closely with the level of the instrument, and the other two are about half a meter above and below it. The HI determination made after the series of pointings across the river is similar, but is derived from pointings to different graduations on the rod. The sequence of observation in the circle left position is to sight to the top, middle and bottom graduation on the rod. In the circle right position, this sequence of observation is reversed.

The largest difference in two such consecutive determinations of HI during Dagana crossing was 0.25mm, while the average difference was 0.13mm. Except when they had to be releveled (which changes the HI), the T-3's seemed extremely stable

and changing observers did not significantly change the computed HI. The standard deviation for a single value of HI was about 0.1mm, which is adequate for the need.

Determination of Target Heights

During the preliminary observations for target heights, the observer bisects the apparent left end of the stripes in the circle left position and the apparent right end of the stripe in the circle right position. For the observations made after the pointings across the river, the observer points, in circle left, on the top edge of the stripe where the yellow and black meet. In circle right, he points on the bottom edge.

Since the stripes are not regular, there is considerable variation in the results of individual determinations, but they adequately average out in deriving the mean values. The mean difference for morning and afternoon values for all four targets on two days is 0.045mm. However, the average value for standard deviation of a single determination is just under half a millimeter. The mean "subtense" distance computed from the vertical angles and assigned target heights was 340.15m. The same distance was measured as 340.00m with the auto-ranger. The average distance between the targets was about 0.675m and, if it is assumed that all the error in the distance is due to incorrect target heights, an average error in the distance between the targets of 0.298mm is indicated. Such an average error in target heights would be quite acceptable.

Observation on Targets Across the River

The first series of observations is made by pointing on the top target and then on the bottom target in circle left position. The sequence of pointing to targets is reversed in circle right position. Thus, the mean time of pointings on both targets will be about the same. After the first set of 5 measurements, the pointing sequence is reversed by starting and finishing observations on the bottom target. While the computations were based on the angle derived from the mean of ten circle left and ten circle right readings on each target, the individual vertical angles observed at Dagana were examined for spread in their value. The average value for standard deviation of a single vertical angle(in a group of ten) was 1.73 second for the first day. The average for the second day's data was 1.57 second.

In addition to the balancing of all observation data by each observer on either side of the river, the side of the river from which the observers start on the first day is also reversed for the second day's observations. This systematic movement of the observers back and forth across the river ensures that the final results are free of any systematic errors of pointing by either observer.

The theodolites are not moved with the observer, since, unlike a level, the telescope can be plunged to balance the collimation error. By leaving the theodolites in place, it is possible to check the apparent change in HI that may occur when the observers interchange places. As stated earlier, the average value for such apparent shift was 0.1mm. It would be hard to prove that the instruments do

not move that much, but even the influence of a larger shift is removed from the difference in elevation between the two marks, computed from observations by both observers and from both sides of the river.

DATA REDUCTION

The computations were carried out using programs written by Hugh Caddess for HP 67/97 calculators. The computation is completed in two stages, each controlled by a separate program. The first program calculates the target height and the HI from vertical circle data. The data are entered as observed and in the sequence they are collected. The Kern rods used are double numbered, i.e. the graduation marked 40 is, in fact, 2.0 meter above the foot of the rod. The nominal values of the rod are entered, as observed.

When the observed circle readings are entered, the program calculates the vertical angles and the collimation values, which are stored in ascending order. The program displays an error message if a change in collimation of about 5" is detected. The operator can then retrieve the largest and the smallest values of collimation to see how much it changed. When such apparent change is 60 or 120 seconds (or 600), evidently a mistake in reading (or recording) the minutes is indicated. Although very few such mistakes were actually encountered, every set of observations on the rod graduations, was automatically checked against such blunders.

The program calculates three values for the horizontal distance to the near rod, corresponding to the angles subtended by the top - bottom graduations, the middle - bottom graduations and the top - middle graduations. The mean value is stored for later use for computing the target heights. Three values for the HI are similarly calculated and stored in ascending order. The highest and the lowest values are examined and recrded, while the mean value is used later for computing the target heights. The largest difference in HI values 0.46mm for Dagana crossing, and the average was 0.12mm.

There is a separation of 0.014m between the face of the target and the graduated invar strip of the rod. The mean horizontal distance computed to the invar strip, earlier, is shortened by this amount for computation of the target heights. Due to the imprecise design of the targets, large apparent changes in collimation are to be expected. During this computation, the program halts briefly and displays the change in collimation and continues on to compute the heights of the targets.

The second program computes the difference in elevation between the two marks indicated as A and B in Fig. 1. The two HI's and the four target heights computed earlier, are entered in addition to the angles to the targets and the EDM distance between the instrument and the far targets. The program computes the difference in elevation from A to B and also from B to A, by interpolating the far rod reading corresponding to the level line of sight. This computation follows the method used with N-III type level, as mentioned

SENEGAL RIVER BASIN
SURVEY AND MAPPING PROJECT

RIVER CROSSING

NEAR BENCHMARK	SAB 1	OBSERVER	Berlynd	T-3#	91249
FAR BENCHMARK	SAB 2	RECORDER	Cisse	EDM #	91160
AREA DESCRIPTION	Dagana	DATE	12 Dec 79	NEAR ROD#	269715
		TEMP	25.8 C	FAR ROD#	269717

NEAR ROD 1st HI SET UP				2nd HI SET UP			
TIME	1022			TIME	1114		
T-CL	92° 29′ 19.3″	ROD RDG	57	T-CL	92° 24′ 29.0″	ROD RDG	56
M-CL	90 01 16.1	ROD RDG	27	M-CL	90 06 13.9	ROD RDG	28
B-CL	89 21 40.5	ROD RDG	19	B-CL	89 21 40.8	ROD RDG	19
B-CR	90 38 22.8			B-CR	90 38 29.2		
M-CR	89 58 49.1	HOR DIS	17.370	M-CR	89 53 53.2	HOR DIS	17.356
T-CR	87 30 46.2			T-CR	87 35 35.0		
		HI	1.337 629			HI	1.337 742
		ΔH	0.03mm			ΔH	0.21mm
T-CL	92 12 21.1	HT	2.676 797	T-CL	92 10 59.4	HT	2.676 341
B-CL	90 33 53.4	HT	1.680 096	B-CL	90 32 23.2	HT	1.680 932
B-CR	87 26 04.0	HN		B-CR	89 24 21.8		
T-CR	87 47 37.7			T-CR	87 46 09.5		

DISTANCE TARGET FACE TO ROD FACE 0.014m
MEASURED DISTANE TO FAR ROD 340.00m

FAR ROD READINGS

POS NO	TOP TARGET CIRCLE LEFT	BOTTOM TARGET CIRCLE LEFT	BOTTOM TARGET CIRCLE RIGHT	TOP TARGET CIRCLE RIGHT	TIME
1	90 01 17.8	89 58 58.4	90 01 07.7	89 58 49.7	1036
2	90 01 14.0	89 59 00.6	90 01 08.3	89 58 49.8	1040
3	90 01 18.8	89 58 59.8	90 01 05.6	89 58 48.3	1043
4	90 01 18.4	89 59 00.0	90 01 05.7	89 58 47.9	1047
5	90 01 18.9	89 59 01.7	90 01 06.5	89 58 49.2	1048
POS NO	TOP TARGET CIRCLE LEFT	BOTTOM TARGET CIRCLE LEFT	BOTTOM TARGET CIRCLE RIGHT	TOP TARGET CIRCLE RIGHT	TIME
1	89 59 00.1	90 01 18.2	89 58 49.7	90 01 06.4	1050
2	89 59 00.4	90 01 19.1	89 58 49.2	90 01 07.5	1052
3	89 59 00.5	90 01 16.6	89 58 49.6	90 01 08.9	1101
4	89 59 00.2	90 01 19.0	89 58 48.8	90 01 06.8	1105
5	89 59 00.6	90 01 18.6	89 58 48.0	90 01 06.2	1108

Fig.3 Observation set from one end of the river.

SENEGAL RIVER BASIN
SURVEY AND MAPPING PROJECT

RIVER CROSSING

NEAR BENCHMARK	SAB 2	OBSERVER	Soumare	T-3#	91160
FAR BENCHMARK	SAB 1	RECORDER	Guisse	EDM #	91249
AREA DESCRIPTION	Dagana	DATE	12 Dec 79	NEAR ROD#	269717
		TEMP	25.5 C	FAR ROD#	269715

NEAR ROD 1st HI SET UP				2nd HI SET UP			
TIME	1025			TIME	1112		
T-CL	91° 21' 12.4"	ROD RDG	50	T-CL	91° 40' 52".2	ROD RDG	54
M-CL	89 13 13.2	ROD RDG	24	M-CL	90 22 09.6	ROD RDG	38
B-CL	88 09 18.2	ROD RDG	11	B-CL	88 53 32.4	ROD RDG	20
B-CR	91 50 36.6			B-CR	91 06 22.8		
M-CR	90 46 43.4	HOR DIS	17.447	M-CR	89 37 45.4	HOR DIS	17.450
T-CR	88 38 43.1			T-CR	88 19 05.6		
		HI	1.674 677			HI	1.674 607
		ΔH	0.11mm			ΔH	0.03mm
T-CL	89 04 53.1	HT	1.115 548	T-CL	89 03 18.8	HT	1.115 210
B-CL	88 20 07.4	HT	0.660 817	B-CL	88 18 32.0	HT	0.659 905
B-CR	91 39 49.8	HN		B-CR	91 38 22.4		
T-CR	90 55 06.4			T-CR	90 53 34.2		

DISTANCE TARGET FACE TO ROD FACE 0.014m
MEASURED DISTANE TO FAR ROD 340.00m

FAR ROD READINGS

POS NO	TOP TARGET CIRCLE LEFT	BOTTOM TARGET CIRCLE LEFT	BOTTOM TARGET CIRCLE RIGHT	TOP TARGET CIRCLE RIGHT	TIME
1	90 02 33.6	89 57 32.6	90 02 26.1	89 57 32.2	1034
2	90 02 32.8	89 57 30.8	90 02 26.2	89 57 24.0	1040
3	90 02 32.8	89 57 33.6	90 02 25.0	89 57 22.8	1043
4	90 02 31.4	89 57 30.8	90 02 25.4	89 57 23.6	1047
5	90 02 33.4	89 57 31.3	90 02 25.3	89 57 24.0	1048
POS NO	TOP TARGET CIRCLE LEFT	BOTTOM TARGET CIRCLE LEFT	BOTTOM TARGET CIRCLE RIGHT	TOP TARGET CIRCLE RIGHT	TIME
1	89 57 30.0	90 02 33.0	89 57 22.8	90 02 24.1	1050
2	89 57 29.1	90 02 32.4	89 57 20.8	90 02 22.8	1101
3	89 57 31.5	90 02 29.8	89 57 22.0	90 02 22.5	1105
4	89 57 30.6	90 02 33.0	89 57 22.2	90 02 25.6	1108
5	89 57 32.0	90 02 34.4	89 57 22.2	90 02 24.8	1110

Fig.4 Observations from opposite end of the river.

earlier, and does not use the measured distance.

Computation of the same difference in elevation is then made using the horizontal distance and separate values from data for each target are reduced. Finally, as a check, the program computes two "subtense" distances, using the vertical separation between the two targets and the mean observed angle between them. The design of the computational procedure thus provides several different checks on the data and its reduction.

RESULTS

The observers for Dagana river crossing included Bryan Berlind who was trained at the Geodetic Survey Squadron of the D.M.A. at Cheyenne, Wyoming, and Amadou Soumaré, a Cartographic Engineer from Mali and initially trained at I.G.N. in Paris. Preliminary trial observations by these well-trained observers indicated that the wider stripes on the targets provided better results for the 300 to 400 meters distance of the crossings along the Senegal River.

The first complete river crossing measurements were made for 340 meter wide Dagana crossing on December 11 and 12, 1979. The set up on both sides was fairly close to the edge of the river, and the line of sight was about 4.5 to 5.5 meters above the water. There was a good breeze on both days and the observers did not experience heat waves on either day.

The vertical angles to each target were meaned in groups of ten, as they were observed, and the standard deviation of a single angle for the group computed. The average value for such standard deviation for 32 groups was $1''.7$. As a single determination of the difference in elevation between the two marks is the computed result of 80 vertical angle measurements(20 measurements by each observer from each side of the river), the expected precision should be related to $1''.7/\sqrt{80} = \pm 0.19$ second. At a distance of 340 meters, such an angular error results in an elevation discrepancy of 0.3mm. This corresponds well with the computed values for the four determinations and is considered adequate. Whenever two determinations differ by a larger amount, it is probably due to some atmospheric anamolies and it is reasonable to believe that merely changing instruments or methods would not significantly affect the results. Some additional details of the results have been tabulated on the following page.

CONCLUSIONS

The use of Wild T-3 theodolite has four advantages over the Wild N-III or other similar spirit level: (1) Exactly as many coincidences of the level vial are needed as the total number of pointings on the targets, instaed of half as many in case of a level. (2) The observations can be computed to give separate values for top and bottom targets, thus exposing systematic errors, if any. (3) A distance can be computed from the observations and compared with directly observed value with an EDM. (4) The least count for the graduated vertical circle of a T-3 is 0.2 second(although the nominal value is 0.1"). For the N-III level, one

micrometer graduation corresponds to about 5 seconds of arc and interpolation to tenths of a division would result in random errors of 0.5 second.

A comparison with Ni-2 observation data appears to indicate a larger spread in the value of angle to the target for T-3. The targets used definitely need to be modified and observations to improved targets are expected to reduce the spread in the T-3 angles. However, the experience gained so far shows that the achievable precision of T-3 angles and the number of observations taken should yield adequate accuracy, provided the atmospheric conditions are good. The rotating wedge method using Ni-2 level may be somewhat superior to the T-3 method used, but in either case, it is likely that atmospheric anomalies will introduce larger errors than instrumental errors. The Wild T-3 or equivalent theodolite is a more standard item in inventory of most geodetic survey organizations, and the results at the Dagana crossing clearly show that the method based on vertical angle measurement with T-3 is acceptable for river crossing.

SUMMARY OF RESULTS AT DAGANA CROSSING

Date	Computed Difference in Elevation(m) Arc Solution (No Distance)	Tangent Solution (Using Distance)
11 Dec am	.480 376	.480 369
11 Dec pm	.480 570	.480 578
11 Dec mean	.480 473	.480 474
12 Dec am	.480 295	.480 292
12 Dec pm	.480 160	.480 145
12 Dec mean	.480 227	.480 218
Mean for all	.480 350	.480 396
Std. Dev. single	.17mm	.18mm
Std. Dev. mean	.086mm	.090mm
11 Dec - 12 Dec	.246mm	.256mm

	Top Target Data only	Observer Berlind	Observer Soumare
11 Dec	.480 457	.480 255	.480 691
12 Dec	.480 329	.480 691	.479 763
Mean	.480 393	.480 473	.480 227

Maximum discrepancy in elevation diff.	.410mm	.433mm

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1. Berry, R.M., Experimental Techniques for Levels of High-precision Using the Zeiss Ni-2 Automatic Level, Proc. 29th Ann. Meet. ACSM, 1969

2. U.S.Coast & Geodetic Survey Special Publication No. 239, Manual of Geodetic Leveling, 1948